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Relation of Fertilizer Balance to Potash Hunger and the Fusarium Wilt of Cotton

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RELATION OF FERTILIZER BALANCE TO POTASH HUNGER AND THE FUSARIUM WILT OF COTTON

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The value of fertilizer combinations, balanced in terms of actual deficiencies of the soil, is recognized in the South as a control for such nonparasitic diseases of cotton as the so-called "rust" (potash hunger). More recently, in many parts of the South, the use of fertilizers containing sufficient potash to overcome the potash deficiency of the soil has been found to be an efficient method of controlling the cotton wilt disease, caused by *Fusarium vasinfectum* Atk., by Rast *(1)*, Young, Ware, and Janssen *(6)*, Young, Janssen, and Ware *(9)*, Ware and Young *(10)*, Young *(12)*, Neal *(2, 4, 5)*, and Miles *(7, 8, 11)*.

In the course of 9 years' work on this subject at the University of Arkansas College of Agriculture, a variety of fertilizer combinations were used *(12)*. Fifteen locations were employed, mostly in the alluvial soils of eastern Arkansas where "rust" (potash hunger) is frequently a complicating factor. In addition to fertilizers that were complete with respect to the three common fertilizer elements (NPK), various incomplete applications were used. It became increasingly apparent throughout the course of this earlier work that, whereas complete fertilizers and high potash applications alone controlled "rust" and reduced the incidence of fusarium wilt, certain of the incomplete fertilizers not only failed to control "rust" and wilt, but seemed actually to bring about an aggravated form of these diseases. This was most pronounced when superphosphate alone was used, but similar results were obtained when nitrogen and phosphorus were used without potash. When nitrogen alone was used there seemed to be an intensification of the symptoms of potash hunger, but the effect on the incidence of wilt was not as distinct. The application of fairly liberal amounts of potash alone, either as muriate of potash or as kainite, to potash-deficient soils never failed to control "rust" and to greatly reduce the incidence of wilt. Coupled with the intensification of "rust" symptoms and the greater incidence of cotton wilt accompanying applications low or lacking in potash, yields were unsatisfactory, often being practically the same as those of nonfertilized check plots.

The results of these previous experiments suggested the need for a study of the effects of a more extensive series of complete and incomplete fertilizers applied to a soil already low in available potash on "rust" and the fusarium wilt of cotton. From this point of view it seemed necessary to think not merely of the ratio of N, P, and K in the fertilizer itself, but also of the balance in relation to what is necessary to supplement the available nutrients of the soil.

Procedure and Results

In 1937 the writers set up a field experiment near LaGrange, Lee County, in fine alluvial soil. The preceding season the land had been planted to Mebane cotton, and the crop had been so severely affected by both fusarium wilt and "rust" that it was almost a complete failure. Mechanical analysis [1] indicated that the soil was a silt loam, and chemical analyses [1] indicated that it was very high in available nitrogen, high in available phosphate, and very low in available potash, with a pH value of 6.5 and a water-holding capacity of 37.7 [2] per cent.

On an area of three-fourths acre, nine fertilizer treatments, replicated six times, were applied to three varieties of cotton. For each of the nine treatments within the six series, plots containing one row of each of the three varieties were planted, making 27 rows per series or 162 rows in the experiment. Rows were 60 feet long and 40 inches apart. The treatments were fully randomized within each series to allow for statistical treatment by the analysis of variance method. In order that the effect of a given fertilizer treatment during the second or third year would not be complicated by the residual effects of preceding treatments, the arrangement of the fertilizer treatments was not modified after the first year but varieties were rerandomized within the fertilizer treatments the second and third years.

On the limited area an attempt was made to formulate a series of treatments that would include as many combinations of high and low amounts of the three fertilizer elements (NPK) as possible. The basic mixture was 600 pounds of a 6-8-6 fertilizer, which in previous experiments had given satisfactory control of "rust" and wilt *(12)*. The methods of fertilization, planting, thinning, cultivation, and harvesting were the standard methods

[1] The writers acknowledge the assistance of L. C. Kapp and O. R. Younge, assistant agronomists, University of Arkansas College of Agriculture, in making the "rapid microchemical" and the mechanical analyses of this soil.

[2] Measured in the laboratory.

for the eastern Arkansas cotton area, as employed on the College's Cotton Branch Experiment Station in Lee County. These methods have been previously described *(12)*. Nitrate of soda, superphosphate, and muriate of potash were used in compounding the fertilizer mixtures.

The schedule of treatments provided for no fertilization, normal or complete fertilization (for this area), and incomplete combinations in which one or more of the three elements differed in amount from that used in the basic mixture (6-8-6).

Cotton varieties used were Half & Half, which experience had shown to be very susceptible to fusarium wilt; Rowden 2088, a moderately resistant variety (generally sufficiently resistant to fusarium wilt for Arkansas conditions); and a highly resistant strain of the Cook variety.[3]

As soon as a trace of wilt appeared the first wilt count was taken, and wilt counts were then made every 10 days. Previous experience had shown that frequent counts are necessary in order that a complete record of all diseased plants may be secured, because plants infected early in the season may wilt, die, and disappear long before the final wilt counts are taken. At each count dead or dying plants were removed and so recorded.[4] This method of recording disease gives an expression of only the percentages of plants affected. The intensity or severity of the damage to each affected plant has not been considered in these data.

Yield records were taken for each row of the experiment, because there are certain effects of fertilizer on ultimate yield over and above that resulting from variation in incidence of wilt and relative intensity of "rust" (potash hunger). These yield data, expressed in pounds of seed cotton per row, and the final wilt percentages have been subjected to analysis of variance *(13)*. Modifications of this method were used and are explained in the appendix. The only statistical measurements used in the text are mean differences required for significance (odds 19:1) and high significance (odds 99:1).

Table 1 presents the total incidence of cotton wilt in Cook cotton, for each of the 3 years. Comparable data for Rowden 2088 and Half & Half are given in Tables 2 and 3, respectively.

An examination of the data given in these three tables reveals that the differences in wilt incidence, resulting from treatment, within any one variety are not as great as the differences between

[3] Cook 912 was employed in 1937 but because of difficulty in obtaining seed of this strain, Cook 307 was substituted in 1938 and 1939.

[4] In the tables only the final percentages of cotton wilt are recorded.

either of the two more resistant varieties and the susceptible variety receiving the same treatments. The variations in wilt intensity resulting from fertilizer treatment within the resistant varieties (Rowden 2088 and particularly Cook) are rather small,

TABLE 1. EFFECTS OF FERTILIZER TREATMENTS ON INCIDENCE OF FUSARIUM WILT ON COOK 307, MARKHAM PLACE, LAGRANGE, ARKANSAS, 1937-39 [1]

Treatment [2]	Mean wilt on Cook 307 [1]		
	1937	1938	1939
	Per cent	*Per cent*	*Per cent*
0-8-0	2.68	5.56	3.50
0-8-6	1.16	4.20	1.36
0-4-12	.45	3.98	.85
6-0-8	.36	4.83	1.80
6-8-0	1.06	9.78	2.00
6-8-6	.16	3.61	1.23
6-12-4	.95	3.53	2.23
6-12-12	.00	4.18	1.38
Check	2.78	7.86	2.55
Difference required for significance — 5 per cent	1.99	4.45	2.07
Difference required for significance — 1 per cent	2.66	5.95	2.77

[1] Cook 912 was used in 1937, but because of difficulty in obtaining seed of this strain, Cook 307 was substituted in 1938 and 1939.

[2] Fertilizers were applied at the rate of 600 pounds per acre.

TABLE 2. EFFECTS OF FERTILIZER TREATMENTS ON INCIDENCE OF FUSARIUM WILT ON ROWDEN 2088, MARKHAM PLACE, LAGRANGE, ARKANSAS, 1937-39

Treatment [1]	Mean wilt on Rowden 2088		
	1937	1938	1939
	Per cent	*Per cent*	*Per cent*
0-8-0	13.13	20.11	4.56
0-8-6	3.76	5.96	1.78
0-4-12	1.45	8.08	1.65
6-0-8	2.20	6.20	1.70
6-8-0	9.28	13.75	5.75
6-8-6	2.00	9.53	3.51
6-4-12	4.21	7.36	2.11
6-12-12	2.78	5.63	1.86
Check	7.11	9.98	7.28
Difference required for significance — 5 per cent	4.12	8.16	1.86
Difference required for significance — 1 per cent	5.52	10.92	2.48

[1] Fertilizers were applied at the rate of 600 pounds per acre.

TABLE 3. EFFECTS OF FERTILIZER TREATMENTS ON INCIDENCE OF FUSARIUM WILT ON HALF & HALF, MARKHAM PLACE, LAGRANGE, ARKANSAS, 1937-39

Treatment[1]	Mean wilt on Half & Half		
	1937	1938	1939
	Per cent	*Per cent*	*Per cent*
0-8-0	69.96	81.71	72.85
0-8-6	40.23	53.21	48.60
0-4-12	46.55	46.55	32.68
6-0-8	33.61	49.36	48.85
6-8-0	60.75	79.10	79.20
6-8-6	39.71	65.33	60.83
6-12-4	44.20	63.88	59.18
6-12-12	34.28	47.53	46.91
Check	59.65	72.96	65.30
Difference required for significance — 5 per cent	14.32	11.14	11.96
Difference required for significance — 1 per cent	19.17	14.91	16.00

[1] Fertilizers were applied at the rate of 600 pounds per acre.

TABLE 4. MEAN EFFECTS OF FERTILIZER TREATMENTS ON INCIDENCE OF FUSARIUM WILT ON THREE COTTON VARIETIES AFTER RECALCULATION AS PROPORTIONS OF TOTALS WITHIN VARIETIES FOR 3-YEAR PERIOD, MARKHAM PLACE, LAGRANGE, ARKANSAS, 1937-39

Treatment[1]	Total wilt incidence due to treatment		
	Cook 307[2]	Rowden 2088	Half & Half
0-8-0	15.8[3]	23.2	14.9
0-6-8	9.1	7.1	9.5
0-4-12	7.1	6.8	8.4
6-0-8	9.4	6.3	8.8
6-8-0	17.3	17.6	14.5
6-8-6	6.8	9.2	11.0
6-12-4	9.1	8.4	11.1
6-12-12	7.5	6.4	8.6
Check	17.8	14.9	13.1
Total	100.0	100.0	100.0

[1] Fertilizers were applied at the rate of 600 pounds per acre.

[2] Cook 912 was used in 1937, but because of difficulty in obtaining seed of this strain, Cook 307 was substituted in 1938 and 1939.

[3] Each of the values in this table was obtained by dividing the sum of all wilt observations associated with a given variety into the sum of all observations associated with any one treatment on that variety. For example: The sum of all the mean wilt observations (percentages) on the Cook variety in Table 1 equals 74.08. That portion of this total that is associated with only the 0-8-0 treatment equals 11.74. Thus the proportion of total disease in Cook associated with the 0-8-0 treatment will equal 11.74 divided by 74.08, or 15.8 per cent. Each of these new values becomes a percentage of the total observed disease within a variety, and variety totals each are 100 per cent. With the marked disparity in varietal response thus removed, it can be seen by inspection whether or not there are any marked differences in response to treatment in different varieties.

as would be expected, since the genetic potentialities for disease within these two varieties would tend to make the actual differences smaller than the differences induced in the very susceptible Half & Half. Table 4 shows that the treatments have a very similar effect on all varieties when the data are recalculated as proportions of the total response within respective varieties.

In the Cook variety in 1937 only four treatments (6-12-12, 6-8-6, 6-0-8, and 0-4-12) caused a statistically significant reduction in disease incidence, as compared to the nontreated check plots, and there were no significant decreases in 1938 and 1939. No significant increases resulted in any year from fertilizer treatment.

In the semiresistant (or wilt-tolerant) Rowden 2088, one treatment (0-8-0) caused a significant increase in disease over the check plots in both 1937 and 1938 but not in 1939. On the other hand, four treatments gave significant decreases in 1937, none caused significant decreases in 1938, and seven resulted in highly significant decreases in 1939. These significant differences resulting from treatment in the two more resistant varieties show considerable variability from year to year. This might be expected in view of the fact that the statistical measurements showed the variances, after removal of the effects of treatment, within these two varieties to be heterogeneous from year to year.

On the other hand, the variations in wilt incidence within the susceptible Half & Half were homogeneous for the 3 years. Thus, it is not surprising that the effects of treatments on wilt incidence were rather consistent in this variety throughout the 3 years' test. This is shown by the fact that significant reductions in wilt, as compared to nontreated plots, were caused by the applications of 0-8-6, 6-0-8, and 6-12-12 fertilizers in all 3 years, and by 0-4-12 in both 1938 and 1939 (the difference for this latter treatment in 1937 was barely below the 5 per cent level of significance). The increases in wilt resulting from treatments in this variety were all nonsignificant, except that associated with the application of 6-8-0 in 1939.

The yield data for Cook, in pounds of seed cotton per 60-foot row, as mean yields for all replicates associated with each fertilizer treatment for the 3 years are presented in Table 5. Comparable yield data for Rowden 2088 and Half & Half are presented in Tables 6 and 7, respectively.

The differences in average disease intensity for the 3 years, and particularly the differences between identical treatments from

year to year, are in all probability due to differences in the weather. Since soil and air temperature, relative humidity, and soil moisture content are each known to affect the severity of this and other fusarium wilt diseases *(3, 17, 19)*, it would be hard

TABLE 5. EFFECTS OF FERTILIZER TREATMENTS ON YIELD OF COOK 307, MARKHAM PLACE, LAGRANGE, ARKANSAS, 1937-39 [1]

Treatment[2]	Mean yield of seed cotton per 60-foot row		
	1937	1938	1939
	Pounds	*Pounds*	*Pounds*
0-8-0	4.40[3]	4.71	4.33
0-8-6	6.41	5.45	4.03
0-4-12	6.81	5.26	3.81
6-0-8	7.00	6.31	4.63
6-8-0	5.45	6.05	5.33
6-8-6	7.85	8.21	5.95
6-12-4	7.31	8.05	6.20
6-12-12	8.36	8.03	6.00
Check	4.66	4.70	3.03
Difference required for significance: 5 per cent	1.15	1.14	.79
Difference required for significance: 1 per cent	1.54	1.52	1.06

[1] Cook 912 was used in 1937, but because of difficulty in obtaining seed of this strain, Cook 307 was substituted in 1938 and 1939.

[2] Fertilizers were applied at the rate of 600 pounds per acre.

[3] Yield figures may be converted to acre basis by using the factor 217.8.

TABLE 6. EFFECTS OF FERTILIZER TREATMENTS ON YIELD OF ROWDEN 2088, MARKHAM PLACE, LAGRANGE, ARKANSAS, 1937-39

Treatment[1]	Mean yield of seed cotton per 60-foot row		
	1937	1938	1939
	Pounds	*Pounds*	*Pounds*
0-8-0	3.13[2]	4.30	3.91
0-8-6	5.05	4.98	4.41
0-4-12	6.16	6.15	4.83
6-0-8	5.71	6.96	5.70
6-8-0	3.38	5.21	5.11
6-8-6	6.00	8.20	7.00
6-12-4	6.11	7.03	6.78
6-12-12	7.35	7.25	6.88
Check	3.45	3.98	3.11
Difference required for significance: 5 per cent	1.18	1.21	.95
Difference required for significance: 1 per cent	1.58	1.62	1.27

[1] Fertilizers were applied at the rate of 600 pounds per acre.

[2] Yield figures may be converted to acre basis by using the factor 217.8.

TABLE 7. EFFECTS OF FERTILIZER TREATMENTS ON YIELD OF HALF & HALF, MARKHAM PLACE, LAGRANGE, ARKANSAS, 1937-39

Treatment[1]	Mean yield of seed cotton per 60-foot row		
	1937	1938	1939
	Pounds	*Pounds*	*Pounds*
0-8-0	1.25[2]	1.48	3.15
0-8-6	2.98	3.80	4.06
0-4-12	3.98	3.80	4.36
6-0-8	2.91	4.21	4.61
6-8-0	2.03	2.51	3.78
6-8-6	3.48	4.68	6.03
6-12-4	3.16	3.96	5.88
6-12-12	5.15	5.68	6.48
Check	1.75	1.56	2.28
Difference required for significance — 5 per cent	.73	.96	.62
Difference required for significance — 1 per cent	.97	1.27	.83

[1] Fertilizers were applied at the rate of 600 pounds per acre.
[2] Yield figures may be converted to acre basis by using the factor 217.8.

to ascertain from the available climatological data just which combinations of these factors had contributed to any or all of the observed differences. Johnson and Wadleigh *(16)* have reported data from which the influence of the various climatological factors on yield of cotton could be determined. However, no such correlation of the ecological conditions with severity of fusarium wilt of cotton has been presented to date.

A comparison of the effects of fertilizer treatments on yield shows that there was no fertilizer applied to any variety in any year that resulted in a significant decrease in yield, as compared to nontreated check plots. The treatment having the greatest effect on reduction in yield was the application of 0-8-0, and this caused a nonsignificant reduction on all three varieties in 1937, and on Half & Half only in 1938. The only other treatment causing a slight reduction was the 6-8-0 application on Rowden in 1937.

All other treatments on all varieties and in all years gave increases in yield, as compared to check plots, and the greater majority of these increases were at or above the 5 per cent level of significance (odds 19:1). In fact in 1939 all treatments resulted in significant increases over check plots on Half & Half, and only 0-8-0 and 6-8-0 treatments failed to give significant increases in this variety in 1937 and 1938.

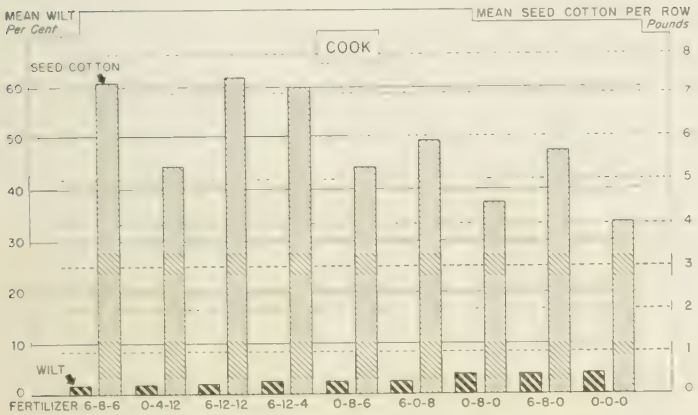

Figure 1. Relation of fertilizer treatments to incidence of fusarium wilt and yield of seed cotton on Cook variety. Data for the 3 years are averaged. (Cook 912 was used in 1937, but because of difficulty in obtaining seed of this strain, Cook 307 was substituted in 1938 and 1939.)

A critical examination of both wilt and yield data will reveal that there are effects of treatment on yield over and above any decrease or increase resulting from relative control of fusarium wilt. For example, the application of 6-8-0 was accompanied by an actual (but nonsignificant) increase in wilt in each variety in some years (Cook in 1938, Rowden in 1937 and 1938, and Half &

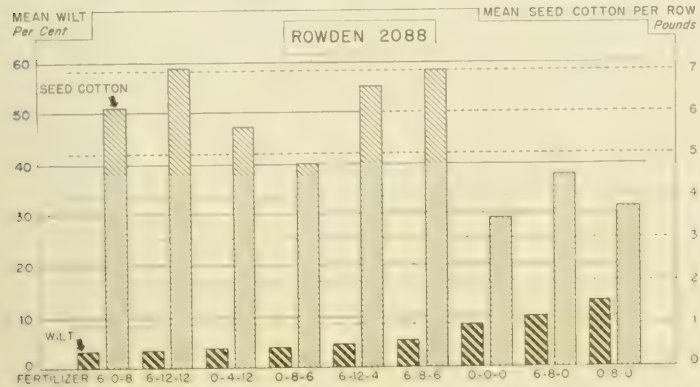

Figure 2. Relation of fertilizer treatment to incidence of fusarium wilt and yield of seed cotton on Rowden 2088. Data for the 3 years are averaged.

TABLE 8. EFFECT OF FERTILIZER TREATMENTS ON REDUCTION (R) OR INCREASE (I) OF FUSARIUM WILT INCIDENCE AND YIELD OF SEED COTTON, AS COMPARED TO UNTREATED CHECK PLOTS, FOR THREE COTTON VARIETIES, MARKHAM PLACE, LAGRANGE, ARKANSAS, 1937-39 [1]

Treatment[2]	Cook 307[3]						Rowden 2088						Half & Half					
	1937		1938		1939		1937		1938		1939		1937		1938		1939	
	Wilt	Yield	Wilt	Yield	Wilt	Yield	Wilt	Yield	Wilt	Yield	Wilt	Yield	Wilt	Yield	Wilt	Yield	Wilt	Yield
0-0-0	R	R	R	I[4]	I	I**	I**	R	I*	I	R**	I	I	R	I	R	I	I**
0-8-0	R	I**	R	I	R	I*	R	I**	R	I	R**	I**	R**	I**	R**	I**	R**	I**
0-4-12	R*	I**	R	I	R	I**	R**	I**	R	I**	R**	I**	R	I**	R**	I**	R**	I**
6-0-8	R*	I**	R	I**	R	I**	R*	I**	R	I**	R**	I**	R**	I**	R**	I**	R**	I**
6-8-0	R	I	I	I*	R	I**	I	R	I	I*	R	I**	I	I	I	I[5]	I*	I**
6-8-6	R*	I**	R	I**	R	I**	R*	I**	R	I**	R**	I**	R**	I**	R	I**	R	I**
6-12-4	R	I**	R	I**	R	I**	R	I**	R	I**	R**	I**	R*	I**	R	I**	R	I**
6-12-12	R**	I**	R	I**	R	I**	R*	I**	R	I**	R**	I**	R**	I**	R**	I**	R**	I**

[1] Comparisons made directly from data in Tables 1, 2, and 3, and Tables 5, 6, and 7.
[2] Fertilizers were applied at the rate of 600 pounds per acre.
[3] Cook 912 was used in 1937, but because of difficulty in obtaining seed of this strain, Cook 307 was substituted in 1938 and 1939.
[4] Practically no change (4.70:4.71).
[5] Nearly significant (2.51 obtained; 2.52 required).
* Difference from check attained significance (odds 19:1).
** Difference from check attained high significance (odds 99:1).

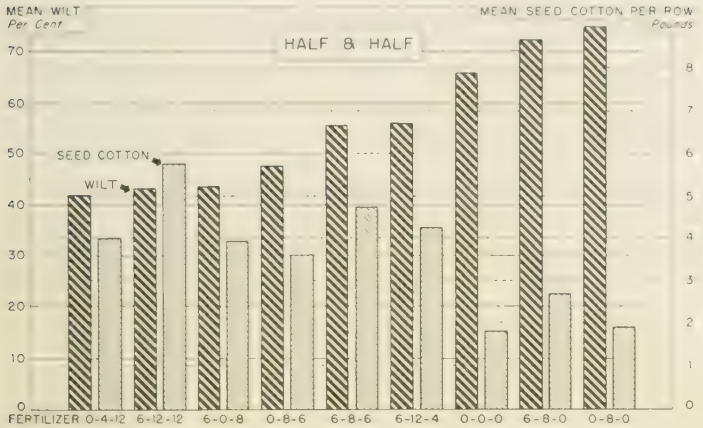

Figure 3. Relation of fertilizer treatment to incidence of fusarium wilt and yield of seed cotton on Half & Half. Data for the 3 years are averaged.

Half in 1937, 1938, and 1939). Yet, despite this trend toward an increase in wilt resulting from the application of 6-8-0, there were increases in yield in all varieties and in all years except Rowden in 1937. However, this treatment caused a significant increase in yield over check plots in only a few instances.

The interrelationships between fertilizer treatment and resulting yield and wilt are presented graphically in Figures 1 to 3. In Table 8 these results are compared in terms of reduction or increase in wilt incidence and yield, showing the effect of each treatment on both wilt and yield.

Discussion of Results

The data presented in the foregoing tables and charts show that great differences in the incidence of cotton wilt and the yields of seed cotton exist within the experiment for each year and from year to year. It may be conceded that seasonal variations, soil variation, irregularities, and inequalities existing among plots with respect to stand and cultivation, and errors in technique may account for some of these variations. The statistical treatment of these data has permitted an estimation of the precision of measurement of all induced effects after allowing for the variability resulting from the above mentioned sources of experimental and sampling errors. These errors are only a com-

paratively small portion of the total experimental variation (Appendix, Tables 1 to 6).

The data presented in Tables 1 to 3 indicate that, under all conditions of the experiment, Cook cotton is very resistant to fusarium wilt, that Rowden 2088 is moderately resistant, and that Half & Half is highly susceptible. The mean percentages of wilt for the three varieties for all treatments for the 3-year period are 2.74 per cent, 6.03 per cent, and 55.66 per cent for Cook, Rowden 2088, and Half & Half, respectively. Variety immediately stands out as the greatest single contributor to variance in the experiment.

Seasonal differences in the incidence of wilt ranging from a mean of 17.94 per cent in 1937 to a mean of 35.69 per cent in 1938 are of a lower order than those attributable to variety, but indicate that environmental factors have considerable effect on the incidence of the disease. The remaining factor to be considered is fertilizer treatment, which is a much more complicated relationship because there were nine separate treatments, including the checks. It was not possible to determine accurately the effect of all variations in the level of each of the three fertilizer elements studied, compared to all possible variations of the others, because of the limitations of space, but those combinations chosen do represent several means and extremes which serve well as a measure of the effect of fertilizer balance in relation to soil needs on incidence of "rust" (potash hunger), incidence of cotton wilt, and yield.

Throughout the 3-year experiment cotton on the nontreated plots showed definite symptoms of "rust" (potash hunger), but no adequate direct measurement of the intensity of this condition was obtained. When superphosphate alone was used such symptoms appeared to be more severe. Similar results were reported by Young (*12*). When superphosphate was used alone (0-8-0) or with only nitrogen (6-8-0), there was a resulting increase in wilt incidence in all varieties in most years.

The application of the standard (or basic) 6-8-6 mixture caused comparatively good reduction in the incidence of fusarium wilt in all varieties in all years. This basic mixture, with only nitrogen omitted (0-8-6), gave a very comparable result to that obtained with the complete fertilizer. Consequently, when omission of both nitrogen and potash (0-8-0) and omission of potash only (6-8-0) caused comparable increases in wilt intensity, it would indicate that the application of nitrogen had little effect

on wilt in this experiment, and that the soil was rather out of balance with respect to the plant requirements for phosphorus and potash. Thus, it might be expected that when nitrogen was omitted, phosphorus decreased, and potash increased (0-4-12), as compared to the basic mixture, the reduction in wilt was greater throughout all varieties and years than that resulting from any other treatment. The complete omission of phosphate (6-0-8) from this basic mixture likewise gave a comparatively good reduction in wilt intensity for all varieties.

These results are rather indicative of the fact that the untreated soil at this locality was favorable to excessive development of cotton wilt because of the high amounts of available phosphorus and an acute lack of available potash. Insofar as wilt is concerned, the available nitrogen seemed to be adequate, since the application of phosphorus alone (0-8-0) gave nearly the same result that was obtained when nitrogen and phosphorus (6-8-0) were applied together.

The variation in wilt intensity, resulting from treatments, during the 3 years was within the limits of a normal population in Half & Half only. This, then, is the only variety in which mean averages of the 3 years' results can be compared statistically

TABLE 9. MEAN EFFECTS OF FERTILIZER TREATMENTS ON INCIDENCE OF FUSARIUM WILT AND YIELD OF HALF & HALF, MARKHAM PLACE, LAGRANGE, ARKANSAS, 1937-39 [1]

Treatment [2]	Mean wilt		Mean yield of seed cotton per 60-foot row	
	Recorded	Difference from check	Recorded	Difference from check
	Per cent		*Pounds*	
6-8-0	74.83	+ 8.86*	1.96	+ 0.10
0-8-0	47.35	−18.62**	3.61	+ 1.75**
0-4-12	41.92	−24.05**	4.05	+ 2.19**
6-0-8	43.94	−22.03**	3.91	+ 2.05**
6-8-0	73.01	+ 7.04	2.77	+ .91**
6-8-8	55.29	−10.68**	4.73	+ 2.87**
6-12-4	55.75	−10.22**	4.33	+ 2.47**
6-12-12	42.91	−23.06**	5.77	+ 3.91**
Check	65.97		1.86	
Difference required for significance	5 per cent	7.499		.519
	1 per cent	9.914		.686

[1] Each value in table represents average of six replicates during the 3 years.
[2] Fertilizers were applied at the rate of 600 pounds per acre.
* Significant.
** Highly significant.

(Table 9). Since the differences in wilt severity between treated and check rows are greatest in this very susceptible variety, a comparison based on the data in Table 9 will clearly indicate the optimum effect on wilt that can be expected from application of this series of fertilizers under these experimental conditions.

On Half & Half all fertilizers containing potash, whether with or without nitrogen or phosphorus, gave a highly significant decrease in wilt over the unfertilized checks as an average for the 3 years (Table 9). The other two fertilizers (0-8-0 and 6-8-0) both caused increases in wilt intensity, with the difference between 0-8-0 and the check being barely significant while the difference between the check and 6-8-0 averages failed to reach a significant (5 per cent) level. These data tend to substantiate the conclusion indicated earlier—that the soil in this experimental plot was extremely out of balance with respect to the plant needs for available potash insofar as the influence on comparative resistance to fusarium wilt is concerned.

It is further seen that with Half & Half the decrease in wilt resulting from additions of an extra amount of potash over and above that needed to give significant reduction continues to give added benefit. This is shown by the greater reduction in wilt resulting from the application of 6-12-12 than from 6-12-4. Furthermore, this increased content of potash in the 6-12-12 application caused a significant difference in reduction over the mixture containing the lowest amount of potash (6-12-4). The mean difference between these two treatments is 12.84 per cent, while a difference of only 9.194 per cent is required for high significance.

The summary of yields, presenting average effects of treatments on Half & Half for the 3 years, shows a mean increase resulting from all treatments, as compared to untreated check plots. All of these increases, except that associated with the 0-8-0 treatment, were highly significant (odds 99:1). This would again emphasize that, though increased yield may, in general, be associated with decrease in the percentage of wilted plants, there can be exceptions, even in a highly susceptible variety, where an application can cause increases in the percentage of wilted plants and increases in yield of seed cotton in the same rows. Conversely, increasing the potash content of a complete fertilizer (6-12-12 as compared to 6-12-4) caused a mean increase in yield that was highly significant, and a mean decrease in wilt that was highly significant.

The yield data for the two resistant varieties also indicate clearly that under the conditions of the experiment all fertilizer applications were definitely beneficial to yields, except the applications of superphosphate alone (0-8-0) or with nitrogen (6-8-0). Increases in yield were, in general, fairly well correlated with control of wilt and "rust." Treatments that eliminated "rust" symptoms and reduced the incidence of fusarium wilt to the minimum were also the treatments that returned the highest yields, whereas treatments lacking potash resulted in the most severe "rust" symptoms and the highest percentages of plants affected with wilt, and also the lowest yields. It was evident that highest applications of potash resulted definitely in the lowest incidence of wilt, but lower applications of potash returned nearly as good yields of seed cotton, indicating that from the practical point of view the optimum amount of potash had been exceeded at least for the wilt-resistant varieties, Cook and Rowden 2088. Tisdale and Dick *(15)* have obtained evidence to indicate that in areas in Alabama the relative resistance of certain wilt-resistant varieties of cotton may be adversely affected by high potash applications. No such results have been obtained at the Arkansas station, but the facts mentioned may indicate the approach to such a condition. In other respects the results reported by Tisdale and Dick are quite similar to those reported herein. However, the nature of the soil and the prevailing environmental conditions might differ sufficiently in these two locations to prevent actual duplication of experimental results.

Throughout the 3-year experiment, yields of Half & Half were decidedly lower than those of the other two varieties, just as the incidence of wilt was far above that in the resistant varieties. According to Humphrey *(14)*, Half & Half is poorly adapted to Arkansas conditions. His data show that this is not entirely because of low yielding properties, but more because of extremely short staple and consequently low price. Where wilt is not a factor this variety is ordinarily considered to possess high yielding properties. In this experiment the 3-year average yield of the Half & Half checks was 405 pounds per acre, in comparison to 899 pounds per acre for Cook and 764 pounds for Rowden 2088. While it seemed impractical to attempt to show statistically the relationship between disease control and yield in this experiment, it is reasonably certain that a large part of the difference in yield exhibited by the three varieties is attributable to the differences in their susceptibility to wilt.

Further analysis of the data presented above, especially that in Table 8 (shown diagrammatically in Figures 1 to 3), will show that from the standpoint of wilt control, the treatments may be divided into four groups. The first group, containing treatments high in potash but lacking either nitrogen or phosphate (0-4-12, 6-0-8, 0-8-6) and the highest analysis complete fertilizer used (6-12-12), was most efficient in the control of wilt. Variations in the incidence of wilt within this group were, for the most part, statistically nonsignificant, and observations indicated further that elimination of potash-deficiency symptoms was obtained only within this group. The omission of either nitrogen or phosphorus, while usually detrimental to yields, compared to the use of the highest analysis complete fertilizer (6-12-12), had no appreciable effect on wilt control.

When complete fertilizers somewhat lower in potash content (6-8-6) and one still lower (6-12-4) were used, the incidence of wilt was much greater than in the preceding group, but within this second group differences were nonsignificant.

Greater percentages of wilt occurred when no potash was applied (6-8-0 and in the nonfertilized checks), and again the differences between the two treatments in this third group were in most all cases statistically nonsignificant. In this group "rust" (potash hunger) was an important factor. As has been pointed out previously, the nonfertilized checks represent an unbalanced condition to which the addition of more nitrogen or phosphorus, or possibly a combination of nitrogen and phosphorus, would tend to aggravate.

When only phosphorus was employed (0-8-0) the condition of unbalance in relation to effect on wilt and "rust" (potash hunger) was still more evident. "Rust" was present in an extreme form and the incidence of wilt was considerably greater than that of the checks in most all varieties in each year.

If the control of wilt was merely the result of providing optimum growth conditions for the host plant, it might be expected that yields would be correlated with wilt control, which is apparently the case. It is true that the three treatments resulting in the highest incidence of wilt have also resulted in the three lowest yields, particularly in Half & Half, and that the highest yield was found in the 6-12-12 plots, which also were in the low wilt group, but here close correlation ends. It seems evident that under the conditions of this experiment a high potash fertilizer is

favorable to both wilt control and high yield, and that fertilizers low in potash and high in nitrogen, and particularly those high in phosphorus, are unfavorable to wilt control and ineffective from the standpoint of yield.

As noted previously, cotton grown on the land the year preceding the setup of this experiment had shown a very high incidence of wilt (more than 50 per cent in the Harper Mebane variety) and also severe "rust" (potash hunger) symptoms. Soil analyses had indicated low amounts of available potash but comparatively high amounts of nitrogen and phosphorus. The nonfertilized checks should, therefore, be thought of as presenting an unbalanced condition with respect to availability of the three substances, nitrogen, phosphorus, and potassium. When additional nitrogen or phosphorus, either alone or in combination, was added, this unbalanced condition might be definitely intensified, but the addition of potash would tend to remedy the unbalanced condition.

The results of this experiment indicate that the application of sufficient amounts of potash to balance the available nitrogen and phosphorus is highly important from the standpoint of controlling "rust" (potash hunger) and wilt. It seems apparent that unless additional amounts of nitrogen and phosphorus are balanced by an additional amount of potash, the cotton plant may actually become more susceptible to both "rust" and wilt than a nonfertilized plant in the same soil.

Summary

During the 3-year period, 1937-39, three varieties of cotton, Cook, Rowden 2088, and Half & Half, were planted on fine alluvial soil at LaGrange, Arkansas. In previous years cotton grown on this land had been seriously affected with fusarium wilt, and had shown severe potash-deficiency symptoms.

Nine different fertilizer treatments, based on 600 pounds of 6-8-6 fertilizer per acre, were used. The fertilizer elements (NPK) were varied to provide a series of complete and incomplete fertilizer combinations, varied from the basic mixture (6-8-6). The treatments were randomized and data were subjected to the analysis of variance.

The mean wilt intensities for the three varieties during the 3-year period were 2.74 per cent, 6.03 per cent, and 55.66 per cent for Cook, Rowden 2088, and Half & Half, respectively. Despite

this wide divergence in comparative susceptibility, the relative effects of treatments were proportionately similar on all three varieties.

Fertilizer combinations containing potash in the lowest amount employed (6-12-4) effectively controlled "rust" (potash hunger) and gave marked reductions in the incidence of fusarium wilt. The highest applications of potash (6-12-12 and 0-4-12) were most effective for the control of wilt.

Unbalanced applications, with respect to potash requirements of the plant (nonfertilized checks, 6-8-0, and 0-8-0), resulted in higher incidence of wilt, accompanied by pronounced symptoms of "rust" (potash hunger). Phosphate alone caused definite increases in wilt over the nonfertilized checks.

All fertilizers employed, except phosphate alone (0-8-0), gave yield increases on Half & Half that were highly significant. The highest application of potash (6-12-12) was more efficient than when the amount of potash was reduced to one-third (6-12-4).

Under the conditions of this experiment, potash applications gave definite control of "rust" (potash hunger) and gave very marked control of wilt, whereas high applications of nitrogen and phosphate, and of phosphate without potash, were either ineffective or even dertimental from the standpoint of "rust" and wilt control.

Increased susceptibility to attacks of fusarium wilt is associated with increased severity of potash-deficiency symptoms in the cotton plant.

It is concluded that under the conditions found in the alluvial soils of eastern Arkansas where these studies were made, fertilizer balance is of great importance in any program for the control of "rust" (potash hunger) and fusarium wilt. High applications of nitrogen and particularly phosphorus, either alone or combined, may actually increase the severity of "rust" and wilt attacks when the applications are made to soils relatively low in available potash.

Appendix

The data from these experiments have been subjected to analysis of variance, following the procedure outlined by Snedecor *(13)*. The disease data have been entered into the analyses as final percentages of wilt and the yield data as pounds of seed cotton per 60-foot row. These analyses have been made for the variance within each variety and within each year for both wilt and yield data, making a total of nine separate analyses for wilt data and nine for yield data. This was necessitated because of the excessive heterogeniety of variances of the wilt data between varieties in any year and between years in any variety except Half & Half. The heterogeniety of wilt differences for varieties is quite beyond the necessity of testing, but that for years within each variety was subjected to the modified X^2 test, utilized by Clark and Leonard *(18)* to test the assumption that each of a set of related variances can be considered a member of a homogeneous population. The resultant X^2 values were 6.848, 9.532, and 2.899 for Cook, Rowden, and Half & Half, respectively. A X^2 value of 5.991 is required for significance at the 5 per cent level (odds 19:1). It is thus shown that the variances for final wilt percentage in the 3 years are homogeneous for only Half & Half. Since variety variances are clearly heterogeneous in any year, it was necessary to test the effect of treatments on disease severity by the use of separate standard errors, each applying only to the variances within one year on one variety.

Similar X^2 tests applied to the variances for yield data show that the 3 years' data within any one variety could be pooled into one analysis. X^2 values found for heterogeniety of years were 5.348, 2.489, and 1.822 for Cook, Rowden, and Half & Half, respectively, where X^2 value of 5.991 was required for significance (odds 19:1). Probably all varieties for all years could likewise be pooled to make one fully combined analysis for yield data for the 3 years. However, since the analyses for wilt data had to be made separately for each variety within each year, the analyses for yield data are presented in the same manner. The only statistical measurements used in the text are the mean differences required for significance (odds 19:1) and high significance (odds 99:1). The analyses for the disease data and the yield data are presented in Tables 1 to 6, which follow.

TABLE 1. ANALYSIS OF VARIANCE OF FINAL WILT PERCENTAGES WITHIN COOK 912, ROWDEN 2088, AND HALF & HALF, MARKHAM PLACE, LAGRANGE, ARKANSAS, 1937

Source of variance	D/F	Cook 912		Rowden 2088		Half & Half	
		Sum of squares	Mean square	Sum of squares	Mean square	Sum of squares	Mean square
Total	53	174.04		1376.06		20542.41	
Treatments	8	50.42	6.30	751.63	93.95**	7917.35	989.66**
Replicates	5	7.46	1.49	124.72	24.94	6587.79	1317.55**
Error	40	116.16	2.90	499.71	12.49	6037.27	150.93

* Significant.
** Highly significant.

TABLE 2. ANALYSIS OF VARIANCE OF FINAL WILT PERCENTAGES WITHIN COOK 307, ROWDEN 2088, AND HALF & HALF, MARKHAM PLACE, LAGRANGE, ARKANSAS, 1938

Source of variance	D/F	Cook 307		Rowden 2088		Half & Half	
		Sum of squares	Mean square	Sum of squares	Mean square	Sum of squares	Mean square
Total	53	875.11		3057.15		14974.15	
Treatments	8	222.72	27.84	1054.51	131.81*	9003.05	1125.38**
Replicates	5	69.95	13.99	36.03	7.20	2321.55	464.31**
Error	40	582.44	14.56	1966.61	49.16	3649.55	91.23

* Significant.
** Highly significant.

TABLE 3. ANALYSIS OF VARIANCE OF FINAL WILT PERCENTAGES WITHIN COOK 307, ROWDEN 2088, AND HALF & HALF, MARKHAM PLACE, LAGRANGE, ARKANSAS, 1939

Source of variance	D/F	Cook 307		Rowden 2088		Half & Half	
		Sum of squares	Mean square	Sum of squares	Mean square	Sum of squares	Mean square
Total	53	167.99		326.36		15043.28	
Treatments	8	31.25	3.90	207.17	25.89**	9972.89	1246.61**
Replicates	5	10.13	2.02	14.34	2.86	852.22	170.44
Error	40	126.61	3.16	104.85	2.62	4218.17	105.45

** Highly significant.

TABLE 4. ANALYSIS OF VARIANCE OF YIELD DATA WITHIN COOK 912, ROWDEN 2088, AND HALF & HALF, MARKHAM PLACE, LAGRANGE, ARKANSAS, 1937

Source of variance	D/F	Cook 912		Rowden 2088		Half & Half	
		Sum of squares	Mean square	Sum of squares	Mean square	Sum of squares	Mean square
Total	53	142.90		151.38		93.16	
Treatments	8	91.19	11.39**	107.64	13.45**	68.45	8.55**
Replicates	5	12.68	2.53*	2.45	.49	8.54	1.70**
Error	40	39.03	.97	41.29	1.03	16.17	.40

* Significant.
** Highly significant.

TABLE 5. ANALYSIS OF VARIANCE OF YIELD DATA WITHIN COOK 307, ROWDEN 2088, AND HALF & HALF, MARKHAM PLACE, LAGRANGE, ARKANSAS, 1938

Source of variance	D/F	Cook 307		Rowden 2088		Half & Half	
		Sum of squares	Mean square	Sum of squares	Mean square	Sum of squares	Mean square
Total	53	145.40		148.55		138.06	
Treatments	8	99.96	12.49**	102.18	12.77**	95.07	11.88**
Replicates	5	7.12	1.42	2.97	.59	12.73	2.54**
Error	40	38.32	.95	43.40	1.08	30.26	.75

** Highly significant.

TABLE 6. ANALYSIS OF VARIANCE OF YIELD DATA WITHIN COOK 307, ROWDEN 2088, AND HALF & HALF, MARKHAM PLACE, LAGRANGE, ARKANSAS, 1939

Source of variance	D/F	Cook 307		Rowden 2088		Half & Half	
		Sum of squares	Mean square	Sum of squares	Mean square	Sum of squares	Mean square
Total	53	84.43		136.46		110.07	
Treatments	8	59.56	7.44**	92.81	11.60**	93.99	11.74**
Replicates	5	6.29	1.25*	17.05	3.41**	4.24	.84*
Error	40	18.58	.46	26.60	.66	11.84	.29

* Significant.
** Highly significant.

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